STATISTICAL CHARACTERISTICS OF Pc3 MAGNETIC MICROPULSATIONS AT LOW LATITUDES

DISSERTATION

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BY

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Certificate

Certified that the work presented in the M. Phil. dissertation entitled **"Statistical Characteristics of Pc3 Magnetic Micropulsations at Low Latitudes"** has been carried out by Mr. Khan Arif Nafees under my supervision.

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Khan Arif Nafees
19-05-05

(Khan Arif Nafees)

Contents

CHAPTER 1

INRODUCTION

The subject of Geomagnetism has been continuously expanding to encompass several branches of physics. Also, in recent years it has proved its usefulness as a tool to delineate the structures of the earth's interior. The earth behaves as a magnet but the origin of the earth's magnetic field is not completely understood and is thought to be associated with electrical currents produced by the coupling of convective effects and rotation in the spinning liquid metallic outer core of iron and nickel. The configuration of these internal currents is such that the field at the surface of the earth resembles that of a dipole or bar magnet near its center.

The earth's magnetic field experiences a lot of disturbances and variations in it. Time variations of the earth's magnetic field are the changes with time of the intensity or direction of the field vector (or its components) at a particular location. At present, they are of practical importance because of their effects on magnetic compass navigation and because of the associated disturbances in radio propagation affecting communication and navigation system. The time variations are, in general, irregular in character, but may be discussed most conveniently in terms of frequency spectrum of their energy content. The variations to be considered in this dissertation originate outside the earth, mainly in the ionosphere and are attributed to solar influences. The spectrum of these variations spans period ranging from a fraction of a second up to several days. The variations or fluctuations of earth's magnetic field ranging in period from about 0.1sec to 10 min. are termed as Geomagnetic Micropulsations. The amplitudes of these fluctuations range from a fraction of gamma ($1\gamma = 10^{-9}$ T) to, on rare occasions, as much as a few tens of gammas. These pulsations are naturally occurring ultra-low frequency quasi-sinusoidal variations (1-10000 mHz) in the earth's magnetic field. The Continuous pulsations in the 22 to 100 mHz frequency range are called Pc3 pulsations.

The studies of diurnal variations of Pc3 period and their dependence on magnetic indices Kp are of vital importance because they provide an understanding of the source and the nature of the waves, which give rise to the magnetic pulsation activity. The present study describes the diurnal occurrence of these pulsations and the dependence of these pulsations on magnetic indices Kp.

The second chapter entitled 'Historical Background and Brief Theory of Magnetic Micropulsations' contains the detail history of earth's magnetic field as well as the interaction of solar wind with earth's magnetic field resulting earth's magnetosphere. The components of earth's magnetosphere and the variation in the earth's magnetic field with their classification are also given in this chapter.

In the third chapter the details of recording instrumentation and analysis are given. The recording and analysis of Pc3 pulsations in south-east Australia at the four stations Newcastle, Broken Hill, Woomera and Launceston was carried out by Ansari et al (1985). The details of recording equipments with their block diagrams are reproduced in this chapter as ready reference.

Chapter 4 is an extension of the work carried out by Ansari and Fraser (1985). In this chapter we have studied the diurnal occurrence of Pc3 for four stations, variations in Pc3 occurrence with Kp values for simultaneously occurring events for stations pairs WM-BH, BH-NC and NC-LN, dependence of Pc3 occurrence probability on Kp values normalized with respect to Kp occurrence at WM, BH, NC and LN and seasonal variation in Kp dependence of Pc3 occurrence over the specified time intervals at Woomera and Broken Hill for data recorded between 25 March to 31 August 1982.

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CHAPTER 2

Historical Background and Brief Theory of Magnetic Micropulsations

2.1 Earth's Magnetic Field :-

The earliest indication of the existence of the geomagnetic field was the direction-finding capability of the compass. The orientation of a freely suspended magnetic needle roughly in the geographical north south direction suggested that the earth behaves as a huge magnet [Russell, C.T. (1995)]. The year 1600 saw the publication of the famous treatise De Magnete by Sir William Gilbert. This treatise consists of six books containing a total of 115 chapters. The central theme of the book is also the title of chapter 17, Book 1:"That the globe of the earth is magnetic, a magnet; how in our hands the magnet stone has all the primary forces of the earth, while the earth by the same powers remains constant in a fixed direction in the universe". Sir Gilbert was first who suggested that the earth behaves as a uniformly magnetized sphere and its magnetism is due to causes within it and not from any external source as was supposed at that time [C.T.Russell(1995), R.A.Wolf(1995)]. It is believed that the source of this field is molten charged metallic fluid in the core of the earth [I.A.Eltayeb et. al. (1984), Goguitchaichvili, 2004]. With the rotation of the earth the fluid also rotates, resulting in the development of circular electric currents in the core of the earth. These currents magnetize the earth. This core is believed to have a radius of about 3500 km [Jacobs, J.A.(1970), Kuang (1997),A.Gailitis et. al. (2001)].

In 1839 Gauss showed that a geocentric dipole is an excellent first approximation to the earth's magnetic field [R. J. Walker et. al. (1995), Jacobs (1970)]. The points where the geocentric dipole meets the surface of the earth are known as geomagnetic poles and the straight line passing through these poles is called magnetic axis of the earth. The direction of magnetic north and that of geographic north differ over most of the globe. The earth's magnetic field is a small magnetic field and is approximately less than one Gauss (Γ) at its strongest near the poles. Its strength is of the order of 10^{-4} tesla. For example, at Aligarh the value of the earth's field is approximately 0.37 gauss $=0.37 \times 10^{-4}$ T.

The magnetic field at a place can be completely described by the three elements known as angle of declination, angle of dip or magnetic inclination and horizontal component of earth's magnetic field. Angle of declination (α) is the angle between the geographic meridian and magnetic meridian at a place. The angle between the earth's magnetic field B and its horizontal component B_H is angle of magnetic inclination. The angle of dip (δ), i. e., magnetic inclination is different at different places on the surface of the earth. At the magnetic equator the angle of magnetic inclination is 0° and 90° at magnetic poles. The third component of the earth's magnetic field is the component of the earth's total magnetic field B in the horizontal direction, i. e.

$$B_H = B \cos\delta$$

The value of horizontal component of earth's magnetic field is different at the different places on the surface of the earth as the value of magnetic inclination is zero ($\delta=0^{\circ}$) at magnetic equator and become ninety ($\delta=90^{\circ}$) at the poles. At any place

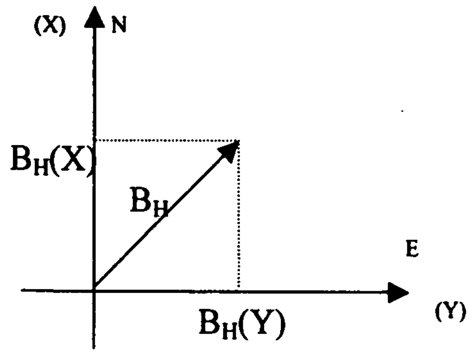
$B_H = B \cos\delta$ and

$B_V = B \sin\delta$

These components give the relations

$B_V / B_H = \tan\delta$

And $B^2 = B_v^2 + B_H^2$



The horizontal component of earth's magnetic field can be further decomposed into two parts as north–south (X) and east–west (Y) components having relation

$$B_H^2 = B_H^2(X) + B_H^2(Y)$$

2.1.1 Variations of The Earth's Magnetic Field: -

The terrestrial magnetic field as measured at the surface of the earth is not constant in time. Its intensity varies and the variation may be broadly classified in two main groups according to their rates as: secular variations and transient variations. The secular variation produces perceptible effects in periods measured in decades or centuries while the transient variations are more rapid and have periods measured in days, hours or even minutes. The range of spectrum of these geomagnetic phenomena is enormous extending and shown in the table given below:

Period		Origin	Comments
Seconds	Years		
10^{17}	3.10^{9}	?	?
10^{15}	3.10^{7}	Internal And Dipolar	Dipole Reversals
10^{10}	300	Internal, Non-dipolar	Secular variation
10^{9}	30		
10^{6}	3.10^{-2}	External	Magnetic storms
10^{5}	3.10^{-3}	External	Diurnal variations
10^{2}		External	Micropulsations
10^{-1}		External	Sub-acoustic

The origin of the secular variation is still not well understood. Results of many Scientific researches suggest that these secular variations of the Earth's magnetic field result from the effects of magnetic induction in the fluid outer core and from the effects of magnetic diffusion in the core and the mantle.[J.Bloxham (1992), Bloxham et. al. (1985), A. Gaguilchachvili (2004)]. The transient variations are now known to be due to worldwide current system, partly in the conducting regions of the upper atmosphere and partly in extra–terrestrial space. For the case of the quiet day type of variations related to the solar or the lunar day, the current systems are produced by tidal motions in the upper atmospheric regions while for the variations associated with the magnetically disturbed days, the corresponding current systems are produced presumably by the entry of high velocity neutral streams of corpuscles into the terrestrial atmosphere.

2.1.2 Magnetic Indices: -

The intensity of magnetic disturbances, shown on the magnetograms of a magnetic observatory, are measured by a figure 'k' between 'O' and '9' for an interval of 3 Greenwich hrs. 0-3,3-6 etc. Thus they incorporate also any local effects such as the systematic diurnal variations in geomagnetic activity. To overcome this problem, a new index 'kp' is used to measure planetary variations in magnetic activity. This index is based on 'standardized' indices, which have been freed as for as possible from local features.

Kp indices are given to thirds, for example the intensity interval 1.5 to 2.5 is shown in Kp as 2_{-}, 2_0 and 2_{+}. This provided 28 grades of Kp from O_o, O_{+}, 1_{-}, 1_o,------- to 8_{+}, 9_{-}, 9_0, by which the whole range of geomagnetic activity, from the quietest conditions to the most intense storm, can be express as a single digit and an affix. This was achieved by a quasi-logarithmic relation between the amplitude of disturbance in the 3 hr interval and Kp. In order to obtain a linear scale, Kp may be converted into a 3 hr equivalent planetary amplitude, a_p, by means of table given below. At a standard station in about 50° geomagnetic latitude, a_p may be thought of as the range of the most disturbed of the three field components expressed in the unit 2γ.

Kp	0_0	0_+	1-	1_0	1_+	2-	2_0	2_+	3-	3_0	3_+	4-	4_0	4_+
a_p	0	2	3	4	5	6	7	9	12	15	18	22	27	32

Kp	5-	5_0	5_+	6-	6_0	6_+	7-	7_0	7_+	8-	8_0	8_+	9-	9_0
$\mathbf{a_p}$	39	48	56	67	80	94	111	132	154	179	207	236	300	400

In general day-to-day changes in the intensity of any disturbance follow a similar pattern over a wide area; similarly, quit conditions are usually widespread. Most days show some magnetic disturbance, but except in periods of very violent activity, it is found that the disturbance D is superposed on a regular daily variation-called the solar daily variation S. S is seen in its pure form on quiet days when it is denoted by Sq. Each magnetic element is affected in a characteristic way by each of the variations S and D. The type and range of variations also vary throughout the year, showing a seasonal change and the range and indices of D also vary from year to year.

The intensity of magnetic disturbances increases from low to high latitudes up to latitude of the auroral zones, i. e., about magnetic latitude 65°. In the high latitudes, magnetograms are seldom completely undisturbed. Intense magnetic storms usually commence suddenly at almost the same instant all over the Earth. In middle and lower latitudes, the horizontal intensity H rises to a maximum within an hour or two of the commencement and remains above its initial value for a period of 2-6 hours. This is called the initial phase. H then decreases, attaining after several hours a minimum, which is much more below the initial undisturbed value than the maximum was above it. This is called the main phase, and is followed by a gradual recovery that may last for several days. The greater the storm, the more rapid is the development of these phases. In addition to large scale magnetic storms there are disturbances of much shorter duration, such as polar magnetic sub-storms and bays.

Abrupt impulsive change (sudden impulses) may also occur and are often observed simultaneously all over the world and have also been detected in the magnetosphere. Variations with periods roughly from 0.1s to 10min. are grouped together and are called geomagnetic micropulsations [Jacobs (1970), R. L. McPherron (1995)].

2.2 THE EARTH'S MAGNETOSPHERE: -

The sun causes wide spread effects on the earth's environment and most of the phenomenon have their origin in processes occurring on the solar surface. In addition to the production of a wide spectrum of electromagnetic radiation (including ultra-violet and X-rays) the sun's outer surface-the solar corona-is continuously being blown away from the sun to form a supersonic outflow known as the solar wind [Anderson,R.Y. (1992)]. This occurs at such a high temperature that the individual atoms are broken up into their constituent ions and electrons. This state is known as plasma state. In a series of papers beginning in 1957 on the investigation of the expansion of the solar corona into interplanetary space, E.N. Parker developed a magneto-hydrodynamic theory of the solar wind. Parker showed that the only reasonable model of the interplanetary medium utilizing all available information on coronal temperatures and densities was of necessity hydrodynamic and, most important, supersonic. The model of the solar wind as developed by Parker has been confirmed by the investigations of interplanetary space by artificial satellites and space probes. These investigations have shown that the interplanetary medium in the vicinity of the Earth is not just empty space but instead is filled with a highly tenuous plasma which is being continuously blown radially out from the sun at speeds averaging 300-500 km/s. This solar plasma consists primarily of ionized hydrogen (protons and electrons) and is electrically neutral having density of the order of 10 ions /cm^3. This solar plasma carries the magnetic field away from the surface of the sun, transporting it through interplanetary space and into the Earth's vicinity. In addition to experiencing all of the hydrodynamic forces of a flowing fluid, plasma also experiences electric and magnetic forces. Thus, a planet's magnetic field represents an obstacle to the flowing solar wind.

When the solar wind reaches the Earth, it interacts with the terrestrial magnetic field, distorting it to form compression on the day side, and a very elongated tail on night side, i.e., away from the sun. The distorted Earth's magnetic field then forms a cavity in the solar wind flow. Thus the interaction of Earth's magnetic field and solar wind makes an elongated cavity by confining one another within which the Earth's magnetic field is constrained. This region that contains the Earth's magnetic field is called **the magnetosphere**, and a demarcation region called **the magnetopause** marks the boundary between this volume and the solar wind. The distance of the magnetopause from the center of the Earth depends on the intensity of the solar wind. The solar wind varies in response to changing conditions on the sun. As a result, the distortion of the Earth's magnetic field, the position of the magnetopause and the size of the magnetosphere also vary [Anderson 1992]. Generally the boundary between the Earth's magnetic field and the solar wind is about 10 Re (earth's radii) from the center of the Earth on the side of the earth toward the sun while away from the direction of the sun, the magnetosphere stretches far out behind the earth, even farther than the distance to the moon which is clear from the fig.1.

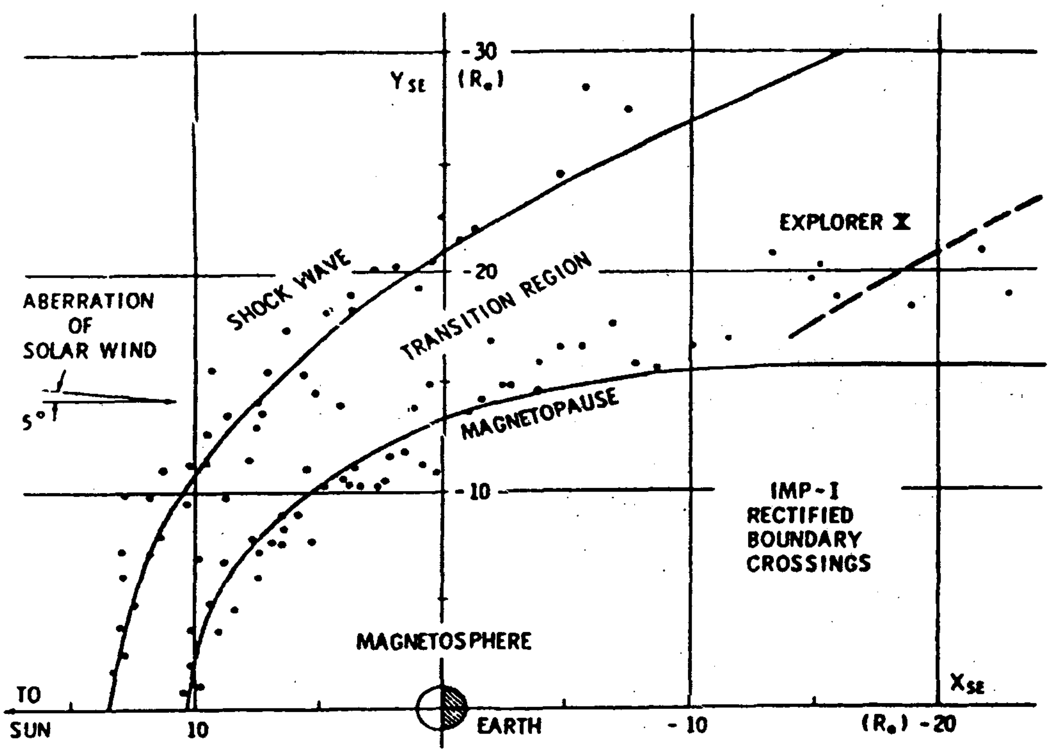


Fig.1 The location of the magnetopause and bow shock (After N. F. Ness)

Earth's magnetosphere consists of several regions that are created by the field topology. The magneto tail is formed by tail lobes and plasma sheet. In the inner magnetosphere we have plasmasphere mapping to mid- and low-latitudes. Overlapping both plasmasphere and inner plasma sheet are radiation belts and ring currents [Russell (1995), W.J.Hughes (1995), Jacobs (1970)]. The approximate configuration of the magnetosphere is shown in the fig.2.

2.2.1 Magnetopause and Magnetosheath:-

In the flowing solar wind, as already noted, ions and electrons are tied to their magnetic field lines. If the flow is deflected for any reason, the field lines will also deform in such a way that each continues to thread the same plasma particle as before. Therefore, when the solar wind encounters the Earth's magnetic field, its particle cannot penetrate. The two fields thus remain separated. The solar wind pushes back the Earth's

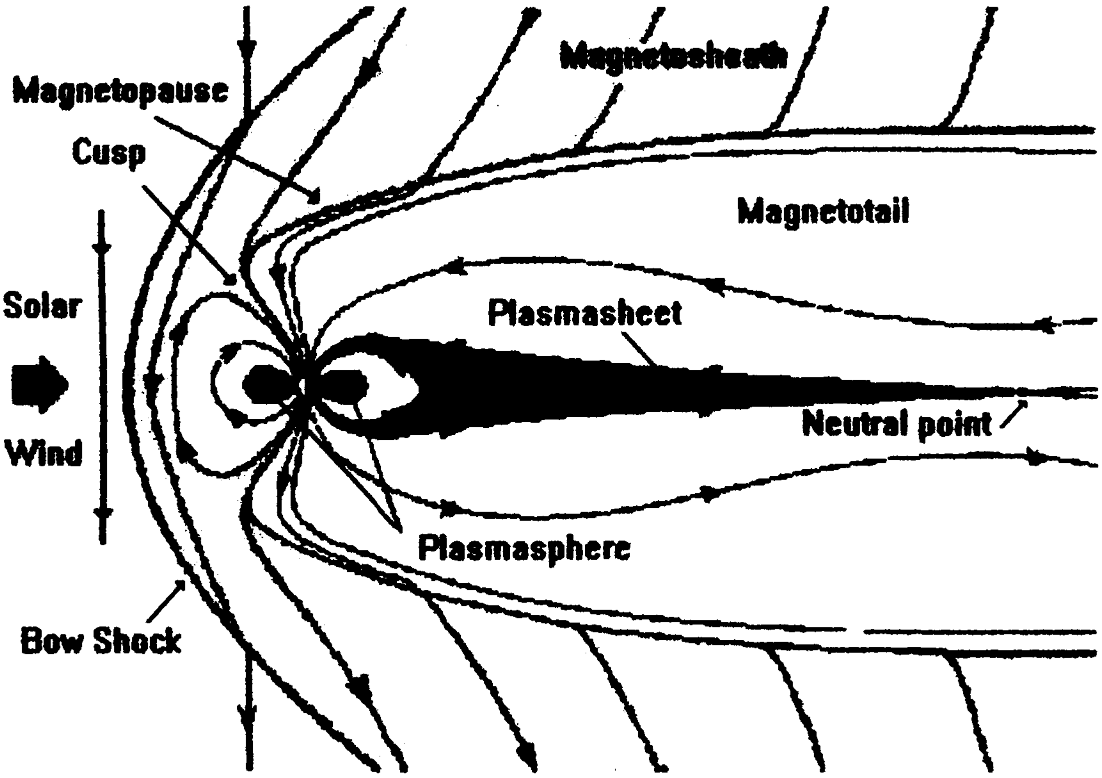


Fig.2 The Approximate Configuration of Magnetosphere

(Website of NASA, USA)

magnetic field somewhat, but ultimately is forced to detour, leaving the Earth's magnetic lines enclosed in a bullet shaped cavity. This cavity continues as a long cylinder on the night side like the tail of a comet. The boundary surface between interplanetary field lines and those of the Earth is called **the magnetopause** [W.J.Hughes(1995), Jacobs(1970)].

This lack of connection between solar wind and Earth's magnetic field insulates the two regions from each other and makes it difficult for the particles and energy to enter the magnetosphere from the solar wind. On the magntopause there are polar cusps that are the points that separate field lines that close on the day side from those swept into the tail. At the cusps, field lines seems to cross each other, implying a magnetic force which has more than one direction, and the only way it could happen is when the magnetic intensity drops to zero, i.e., there is no field at those points. Such a neutral points are weak spots of the magnetopause. Satellites which have probed their vicinity found disordered weak fields rather than well-defined neutral points, and a 'funnel' of solar wind plasma, penetrating along field lines all the way to Earth.

The nose of the magnetopause is on average 10-11 earth radii from the center of the Earth, though the distance varies with the speed and the density of the solar wind. When these are low, the push of the solar wind is weak and the boundary can move out to 13 earth radii. On the other hand, the arrival of fast plasma clouds from solar eruptions can push the boundary until it crosses the synchronous orbit (almost down to half its usual distance), as may happen a few times a year. Because of the speed of the solar wind, a bow shock is formed about 3-4 Re outside the nose, like the shock front ahead of a supersonic aircraft. The region between the magnetopause and the shock wave is called the **magnetosheath** or **transition region**. The presence of the magnetized Earth has little or no effect beyond this transition region [Walker et. al. (1995), Hughes(1995), Jacobs (1970), M.I.Pudovkin et. Al. (1985)].

2.2.2 Earth's Magnetic Tail:

In contrast to the dayside magnetosphere, compressed and confined by the solar wind, the night side is stretched out into a long '**magnetotail**'. This part of the magnetosphere is quite dynamic. Large change can take place there and ions and electrons are often energized. The magnetotail is also the main source of the polar aurora [J.L.Burch et. al. (2001), Hughes (1995)]. Even before the space age observers noted that in the arctic winter, when the sky was dark much of the time, the brightest aurora were seen in the hours around midnight. It was widely believed then that auroral electrons come from the sun, but the fact that aurora seemed concentrated on the side facing away from the sun puzzled everyone. The observations made much more sense about it after the satellites discovered and mapped the magnetosphere's long tail.

Most of the volume of the tail is taken up by two large bundles of nearly parallel magnetic field lines. The bundle north of the equator points earthwards and leads to a roughly circular region including the northern magnetic pole, while the southern bundle points away from Earth and is linked to the southern polar region. These two bundles, known as the 'tail lobes' extend far from Earth and are found even at 200-220 Re (earth radii) from Earth. At these distances some solar wind plasma already penetrates the lobes, but near Earth they are almost empty.

This extremely low density suggests that field lines of the lobe ultimately connect to the solar wind. Somewhere far down stream from Earth. Ion and electrons then can easily flow away along lobe field lines, until they are swept up by the solar wind. But very, very few solar wind ions can oppose the wind's general flow and head upstream, towards Earth. With such a one-way traffic, rather little plasma remains in the lobes [Mughees (1995), Frank (2002)]. There is strong evidence that the tail lobe normally lies on open magnetic-field lines [Wolf (1995)].

2.2.3. The Plasma Sheet and Plasmapause: -

Plasma sheet is a layer of weaker magnetic field and denser plasma, which separates the two tail lobes. It is centered on the equator and typically 2-6 earth radii thick. Unlike field lines of the tail lobes, those of the plasma sheet do cross the equator, though they are quite stretched out. A weak magnetic field means that the plasma is less restrained here than nearer to Earth, and on occasion it slashes or flaps around. In the adjacent region to the magnetotail, the intensity of the magnetic field sharply decreases inside the sheet. The sudden change of magnetic field indicates the existence of strong current flowing in the sheet perpendicular to the magnetic lines of forces. [Hughes (1995), Wolff (1995), Burch J.L. (2001), Jacobs (1970)].

Another distinctive feature of the internal magnetosphere is the plasmapause. It is a three dimensional field aligned boundary in deep magnetosphere which is asymmetric - for moderately disturbed days (Kp=2-4) there is a broad minimum in geocentric radius near dawn and near dusk a bulge with equatorial radius 1-2 Re larger than that of dawn as shown in Fig.3 [Jacobs(1970)]. The mean equatorial radius of the plasma pause is typically about 4 Re, but variation is found from about 7 Re during extremely quite periods to 2-3 Re during great storms. The closed field lines portion of the Earth's magnetosphere has been divided into two physically distinct regions by this boundary.

D.L. Carpenter (1966) found two basic types of drift motions of the plasma inside the boundary. The first is slow 'breathing' motion during which the plasmapause may be thought of as fixed in space with the plasma inside approximately co-rotating with the Earth and also drifting inward and outward in conformity with the asymmetries of the boundary.

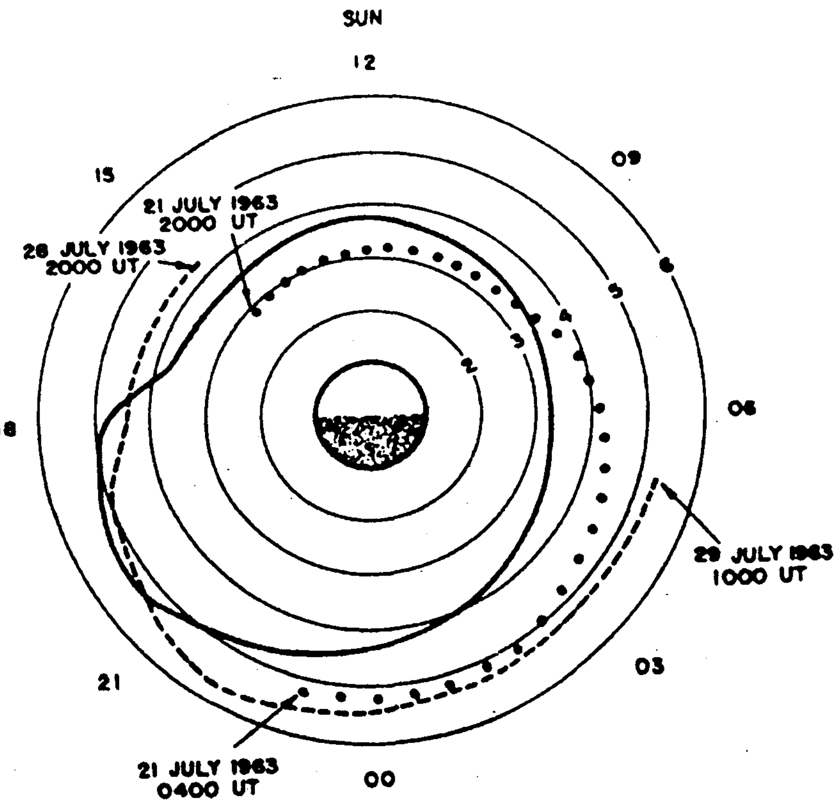


Fig.3 Equatorial radius of the plasmapause vs local time. (After D.L. Carpenter)

The other type of motion is of short duration (1~2 hrs) and involves change in the boundary itself. Such motions usually take place during polar substorms and occur on the night side of the Earth near the longitude where the substorm is observed [Jacobs, (1970), Wolf (1995)].

2.3 <u>Magnetic Micropulsations and Their Classification</u> :-

Geomagnetic micropulsations are short period low amplitude quasi-sinusoidal fluctuations of the earth's magnetic field and have been attributed to hydromagnetic waves within the magnetosphere. The frequencies of these pulsation ranges from approximately 2 mHz to 10 Hz and the amplitude ranges from a fraction of a nano tesla (nT) at the equator to several hundred in the auroral zones.

The observations of these pulsations may be performed by number of ways, such as –

(1) By recording the time derivative of the magnetic elements (induction magnetograph).

(2) By recording Earth currents.

The frequency response in each case will be different and care must be taken in comparing results obtained by different means.

Classification:-

The old classification, based on morphological properties, divided micropulsations into three categories:

(1) Continuous Pulsations (Pc): -

In this group the pulsations with periods usually in the range from 10s to 60s and having amplitude of the order of one tenth of gamma are placed. These are a series of pulsations lasting for many hours and the maximum occurrence frequency is during the morning hours.

(2) Pulsation Trains (Pt): -

These appear as several series of oscillations, each series usually lasting from 10 to 20 min. and the whole phenomenon lasting for not more than about one hour. These are usually having amplitudes greater than the order of 0.5γ. The maximum occurrence frequency is at or before midnight.

(3) Giant pulsations (Pg): -

These are a series of pulsations of large amplitude appearing only in or near the auroral zones. The period is longer than that of the Pc's and the duration is of the order of an hour or more.

There was no unique form of classification until 1960. From the experimental knowledge, particularly which was obtained since the IGY (International Geophysical Year), it has been recognized that micropusations may be divided into two main classes as given below-

(1) Continuous Pulsations (Pc): -

The pulsations that are regular and continuous in nature are called continuous pulsations. Their period ranges from 0.2 to > 600 sec.

(2) Irregular pulsations (Pi): -

The pulsations, which are irregular in nature, are called irregular pulsations. Their periods range from 1 to >150 sec.

Both types of pulsations are further classified into sub-groups, depending on their periods, as given in table below:

Table-1

Classification of Continuous pulsations

Notation	Period Range (Second)	Frequency Range mHz
Pcl	0.2 - 5	200 - 5000
Pc2	5 - 10	100 - 200
Pc3	10 - 45	22.2 - 100
Pc4	45 - 150	6.7 - 22.2
Pc5	150 - 600	1.7 - 6.7
Pc6	> 600	< 1.7

Table -2

Classification of irregular pulsations

Notation	Period Range (Second)	Frequency Range MHz
Pi 1	1 - 40	25 - 1000
Pi 2	40 -150	6.5 - 25
Pi 3	>150	< 6.5

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Chapter-3

Recording Instrumentation and Analysis

3.1 Introduction: -

Geomagnetic micropulsations are fluctuations of Earth's magnetic field whose amplitude range from a friction of a gamma (1gamma=10^{-9} tesla) to, on rare occasion, as much as a few tens of gammas. These geomagnetic micropulsations are divided into different sub-groups depending upon their periods as Pc1, Pc2, ------ Pc6 and Pi1, -- Pi3. One of these sub-groups, the Pc3 magnetic pulsations are quasi-sinusoidal variations in the earth's magnetic field in the period range 10-45 seconds. The magnitude of these pulsations ranges from a fraction of a nT (nano Tesla) to several nT [Orr,D.(1973)]. These pulsations can be observed in a number of ways. The most commonly used techniques are the following-

(i) The magnetic components of the fluctuations are measured employing rapid run magnetometers. These include the flux gate and Rb-vapour magnetometers.

(ii) The time derivative of the magnetic components of the variations is recorded using induction coils.

(iii) The potential difference induced by pulsation magnetic field between the electrodes buried in the earth is measured.

The application of ground-based magnetometer arrays has proven to be one of the most successful methods of studying the spatial structure of hydromagnetic waves in the earth's magnetosphere [Jacobs, J.A. (1970), McPherron, R.L. (1995)]. With a few exceptions, the Pc3 studies undertaken in the past have been confined to middle and high latitudes. The spatial and temporal variations observed in wave polarization and signal phase are of vital importance because they provide evidence which can be directly related to wave generation mechanisms both inside and external to the magnetosphere. At low latitudes ($L \leq 3$) wave energy predominates in the Pc3 band and the spatial characteristics of these pulsations have received very little attention in the past.

An array of four low latitude induction coil magnetometers was established in south-east Australia to study the characteristics of low latitude Pc3 magnetic micropulsations over a longitudinal range of 17° at L=1.8 and a latitudinal range of 10° over L=1.8 to 2.7. The recording stations network array is shown in Fig-1 and station locations and interstation distance are listed in table-1 and table-2 (Ansari et al, 1985).

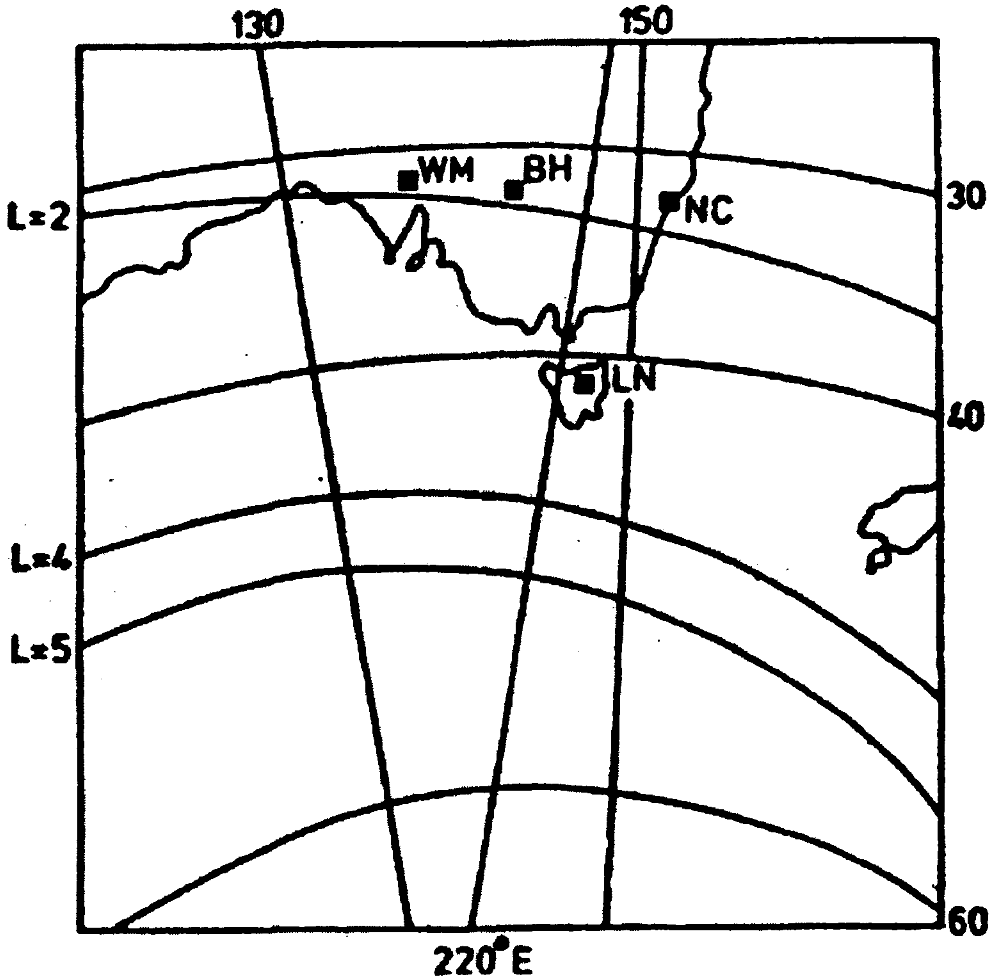

Fig. 1. Pc3 recording stations network (WM-Woomera, BH-Broken Hill, NC-Newcastle, LN-Launceston) (After Ansari et al, 1985)

Table 1

Coordinate details of four Pc3 recording stations(After Ansari et al, 1985)

Station	Geographic		Geomagnetic		L Value
	Φ(˚S)	λ(˚E)	Φ(˚S)	λ(˚E)	
Newcastle (NC)	32.6	151.7	42.0	226.3	1.81
Broken Hill (BH)	32.0	141.5	42.4	214.5	1.81
Woomera (WM)	31.1	136.7	41.7	209.1	1.79
Launceston (LN)	41.7	147.2	52.4	231.1	2.69

Table 2

Interstation distances of the four Pc3 recording stations in Australia(After Ansari et al, 1985)

Station pair	Interstation Distance
WM-NC	425Km
BH-NC	1065Km
WM-NC	1485Km
NC-LN	1120Km

3.2 RECORDING EQUIPMENT: -

The recording and analysis of Pc3 pulsations in south-east Australia was carried out by Ansari et al (1985). The details are reproduced here as ready reference.

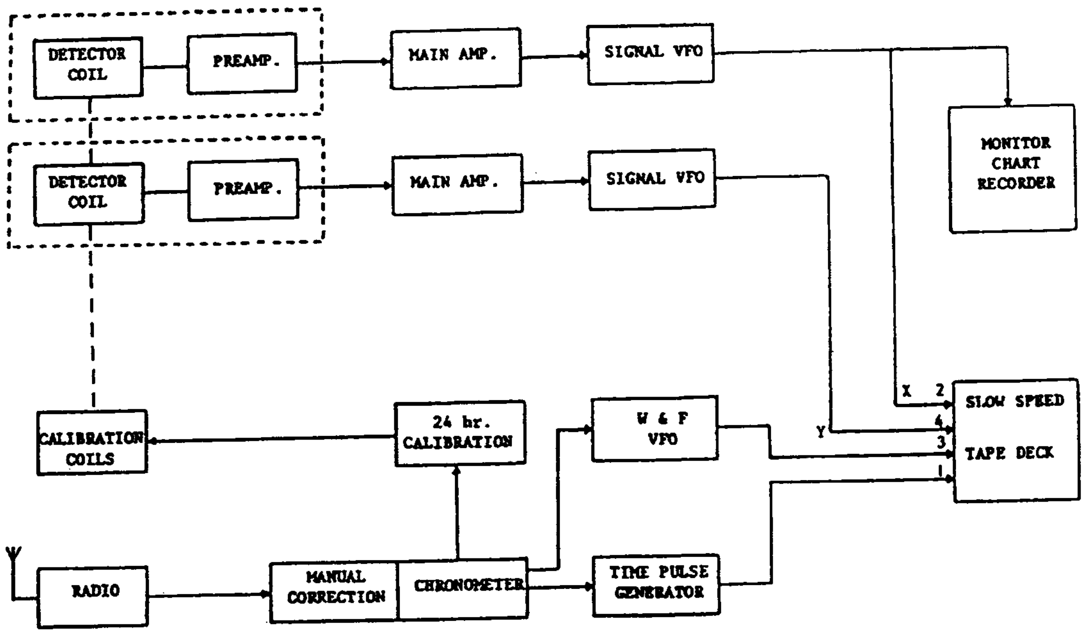

Fig. 2. The block diagram of the university of Newcastle recording system employed at all the four stations(WM, BH, NC and LN) **(After Ansari et al, 1985)**

Fig.2 shows the block diagram of the recording system. The system was designed to record Pc3 pulsations of the geomagnetic field on slow-speed magnetic tape incorporating accurate timing to enable a detailed study of pulsation properties to be carried out. Two components were recorded in the tape, the X-component (geomagnetic north-south) and the Y-component (geomagnetic east-west).

Fluctuations in the geomagnetic field induced a small voltage in the detector coil that was then amplified by a solid state preamplifier situated within the coil containers and a main amplifier 100 meters away in the equipment carvan. A frequency modulated recording system was employed with a variable frequency oscillator (VFO) centre frequency of 6.25 Hz. In addition to the two signal VFOs, a 6.25 Hz square wave signal was recorded to provide wow and flutter correction during analysis. The minimum detectable signal was measured to be 0.1 nT at 50 mHz. The timing system consisted of a chronometer accurate to 10 msec per day, which provided pulses at a number of intervals. The main timing channel consisted of regular 5-sec pulses with 1-min and 20-min interval pulses delayed by 1.5 and 3.5 sec respectively. At 24-hour intervals, four sinusoidal frequencies in the range 25-60 mHz were fed to the detector coils to provide frequency calibration over the operating band width of the system.

The slow speed tape deck operated with a transport speed of ~ 57 cm per hr. and had four recording channels on a ¼ -inch tape. There were (i) the 5-sec pulses, (ii) the X-channel, (iii) the wow and flutter signal and (iv) the Y-channel. An Easter line Angles chart-recorder operating at 3.8 cm per hour provided a visual monitor of the X-channel. The recording system operated from the 250V, 50Hz power mains with battery standby, which was being continuously charged while in use.

3.3 DESCRIPTION OF THE MAIN COMPONENT OF THE RECORDING INSTRUMENTATION (After Ansari et al, 1985)

3.3.1 Detector coil: -

Each detector coil consisted of 250,000 turns of 42 SWG enamel-covered copper wire wonned on four frames. The core consisted of mumetal strips laminated to form a high permeability core. The coil was in a PVC casing within the main PVC coil housing. A calibration coil of 20 turns was wonned around the centre of the inner casing. The main casing had waterproof end caps and cable feed through seals. Each coil had a measured inductance of 7000 Henry and a measured resistance of 36 Kohm.

3.3.2 Solid State Preamplifier: -

The input stage employed a low noise integrated instrumentation operation amplifier (LM725A). Another operational amplifier was used as a driver output stage. To remove 50 and 100Hz power mains noise a pair of twin-T notch rejection filters was placed between the coil input and the input operational amplifier, and another pair between the two operational amplifiers. The minimum detectable signal was in the range of 0.1 nT over the Pc3 band (22-100mHz). The preamplifier was connected directly to the detector coil and contained within the main coil container.

3.3.3 Amplifier and Voltage Controlled Oscillator: -

The output of each preamplifier was led by 100-m coaxial cable to the main equipment carvan and was further amplified by an AC coupled amplifier. Following an input twin-T rejection filter at 50 Hz there was a two-stage operational amplifier. The gain was adjustable and limiting was used to restrict the signal voltage range so that the following VFO did not exceed ± 50% deviation in its FM output. The modulated signal from VFO was fed to the tape heads by a current driven amplifier.

3.3.4 Tape Deck: -

The tape deck consisted of standard Sony TC 105 reel-to-reel deck fitted with a slow-speed motor and a gear box. The deck accommodated 7-inch spools of ¼ -inch tape and was fitted with a four track in-line head. A 550 meter tape recorded continuously for about 38 days. The 250 rpm synchronous motor connected to the flywheel driven by a 125:1 reduction gearbox ratio giving a tape speed of 57cm per hour.

3.3.5 Calibration unit: -

This unit produced four sine waves having frequencies from 25 to 60mHz. The output was applied to the calibration windings of the detector coils once in every 24 hr.

A block diagram of the unit is shown in Fig.-3 given on next page. Four phase-shift oscillators were used to produce sine waves of approximate period of 16, 24, 30 and 40 seconds. Each oscillator was reset by 24 –hr pulse, which ensured start-up of the phase shift oscillators. The 24-hour and 20-min pulses from the chronometer were applied to the input gating circuit, which was fed to the counter. When a 24-hr pulse was received, the input gate opened allowing 20-min pulses to be counted by a BCD up-counter. After four pulses were counted a reset pulse was fed back to the input gating circuit and the counter stopped. This pulse train was then used to drive a four-channel analog data selector.

The analog selector was strobed so that the output was zero at all other times. The calibration signal was then fed to the calibration coil through a voltage divider and series resister.

Manual calibration could be effected at any time by the 24-hr button on the front panel. The 24-hr would not have started until the next 20-min pulse was received and would have cycled for 2-hr 20-min before turning off.

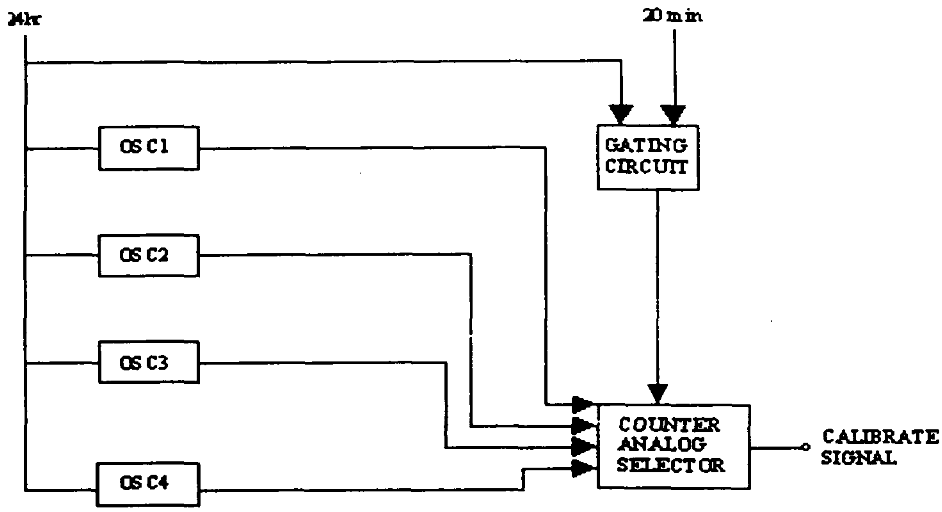

Fig. 3. Block diagram of Pc3 calibration unit **(After Ansari et al, 1985)**

3.3.6 Time Pulse Unit: -

This unit consisted of timing circuits used to produce the pulse widths and delays required for the 5-sec time channel. All pulses were of 10-msecduration, and the 1.5 and 3.5sec delays in the 5-sec pulses, respectively at 1-min and 20-min intervals were provided. The time-pulse output was fed directly to the tape head.

3.4 Analysis and processing System(After Ansari et al, 1985)

Both analog and digital analysis procedures were applied to the recorded data. These two different processes are illustrated in the flow chart in Fig-4. Analog analysis is not described here in detail because most of the work was done in digital analysis.

For digital processing the time-varying signal-channel voltage must be converted to time series. For all data the digitisation intervals chosen was 5 sec., providing a Nyquist frequency of 100 mHz.

The primary processing was accomplished using method II in Fig-4. Data were digitised using a PDP-11/10 minicomputer, which was a *facility for digitising anolog signals varying over a* 4-V range. Two Fortran programs were developed to digitise the Pc3 signals using time information from the tape to control the process. The first program DIGXY1was applied to data with clean 5-sec pulse. The second program DIGXY2 was used for a noisy timing channel, which sometimes occurred due to external interference.

The digitizing system is illustrated in Fig.4. The FM tapes were played back at a speed of 19 cm per second on a 4-channel Akai GX-630D-SS tape deck through electronic circuitry which performed appropriate functions on the time and signal channels as follows.

(i) The 5-sec pulses from track 1 were used by the computer to perform the analog-to-digital (A-D) conversion.

(ii) In addition to regular 5-second pulses there were 1 min and 20 min. interval pulses delayed by 1.5 and 3.5 sec. Respectively.

(iii) The Pc3 X output signal from track 2 and Y signal from track 4, each passing through a frequency demodulator, were fed to analog inputs on the PDP-11/10 minicomputer for digital conversion.

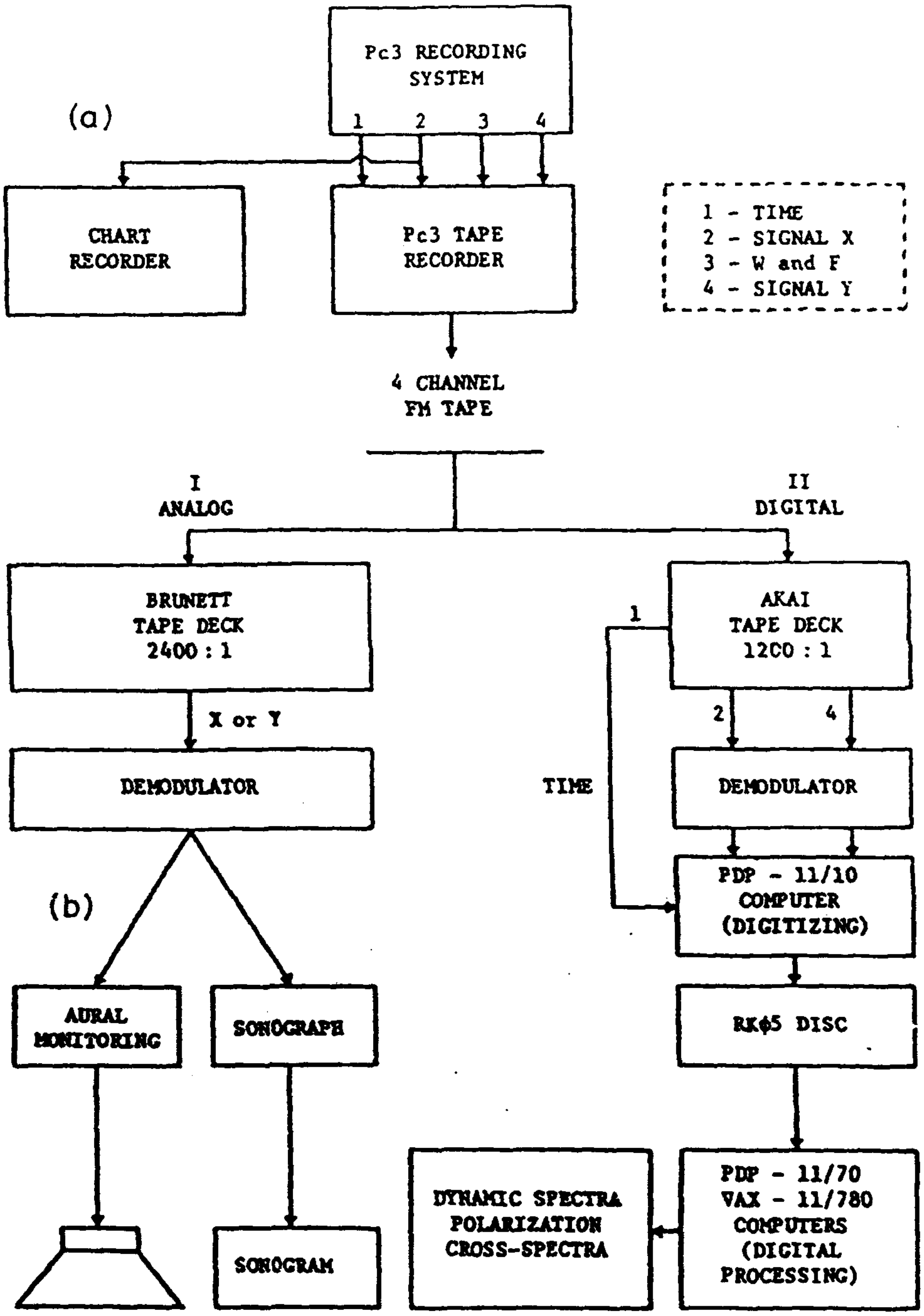

Fig. 4. Pc3 data processing sequences [(a) field recording instrumentation and (b) laboratory analysis instrumentation] **(After Ansari et al, 1985)**

It was essential in the digitizing process that no time lag was introduced by magnetic tape head misalignment during recording and playback. When a particular day was chosen for analysis, the tape was first replayed and the 60-mHz calibration signals at the beginning and end of the day were monitored on the cathode ray oscilloscope (CRO) in XY plane. These signal levels were then adjusted to be within the ± 2 V range of the A-D converter.

The start time of the data to be digitized was set by monitoring the 24-hr calibration on the X-channel (track 2) and the 20-min interval pulse time shifted on track 1. There was a choice of starting the digitisation on 20-min or 1-min interval pulse. Once the preset starting point was reached, a delay may be optionally employed precisely to position the commencement of digitisation. If there was no delay then digitising started at the first 5-sec pulse encountered after the 20-min or 1-min start.

The data were converted into a 8 bit binary integers representing 256 amplitude levels. However, levels up to 252 only were used for the signal and the following numbers replaced the data sample value whenever a time pulse occurred.

(i) 254-1 min. interval pulse

(ii) 253-20 min. interval pulse.

This, therefore, allowed the digitisation process to be time-checked from a data listing. The digitisation programs also had the option of printing diagnostic information on the position of the various time pulses and the range of the data values. The size of the computer core memory allowed data blocks of 25 hr (18 K data samples) of X and Y signal channels to be digitised from 0000 hrs AEST of a particular day to 0100 hrs AEST of the next day. The data were stored on a RKΦ5 magnetic disc and later transferred to the PDP-11/70 and VAX-11/780 computers for processing.

The Pc3 data from all the four stations for the period 25 March to 8 June 1982 were commonly digitised using the above procedure. Additional days in June, July and Aug. 1982 were also digitised for WM, BH and NC. Further more some days in Sept. 1982 were also digitized for WM and BH. An example of amplitude time record at Broken Hill on 20 Sep. 1982 is shown in Fig.-5(Ansari et al, 1985).

The resulting X(t) and Y(t) time series for each station are used to study interstation spectral, polarization and phase characteristics of Pc3 pulsations. This enabled to identify the generation and propagation characteristics of these waves.

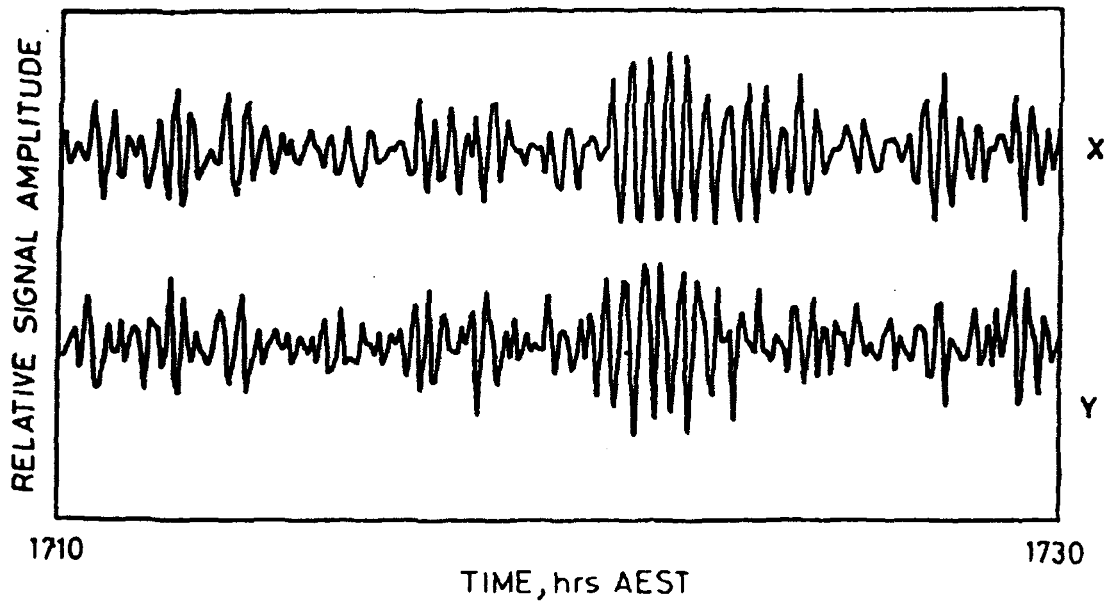

Fig. 5. An example of amplitude time record of a series of Pc3 wave trains recoded at Broken Hill (After Ansari et al, 1985)

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Chapter-4

Results and Discussion

4.1 Introduction: -

It is generally accepted that some of the dayside Pc3 pulsations energy is associated with sources external to the magnetosphere. Statistical studies show that the Pc3 wave period is strongly correlated with the magnitude of the interplanetary magnetic field while the pulsation occurrence rate is dependent on the orientation of the interplanetary magnetic field [Ziesolleck, C.W.S. (1993), Greenstadt, E.W. et. al. (1980)]. Direct evidence for the propagation of external Pc3-4 wave power into the magnetosphere has been presented by Greenstadt et al [1983], who showed that similar wave frequencies were observed simultaneously by ISEE-1 (International Sun Earth Explorer Satellite) and ISEE-2 spacecraft in the magnetosheath and the outer magnetosphere respectively. Lower power was seen within the magnetosphere. In contract to the external source, waves generated within the magnetosphere must originate from instabilities or free energy sources.

The studies of diurnal variations in Pc3 period and their dependence on Kp are of vital importance because they provide an understanding of the source and the nature of the waves. The present dissertation describes the statistical characteristics of the low latitude Pc3 pulsations using induction coil magnetometers employing digital analysis techniques and is the extension of the work carried out by Ansari and Fraser (1985) that is described below.

4.2 Statistical Characteristics: -

A FORTRAN computer program was developed to construct digital sonagrams from the X(t) and Y(t) time series for each recording station of approximately 1-day (25 hour) intervals using the maximum entropy method (MEM) on 10-min subsets overlapping by 5 min. Digital sonagrams of about six months of data were made. An example of digital sonagram is shown in Fig. 4. A detailed analysis of the digital sonagrams characteristics was then carried out and the duration of Pc3 occurrence to the nearest 5 min along with the signal frequencies was then determined.

The diurnal variation in Pc3 occurrence at all the four stations over the period of 25 Mar.-8 June 1982 is shown in Fig-4.1(a) to Fig-4.1(d). The Pc3 occurrence at WM, BH and NC maximize between 1200 and 1300 hrs AEST with maxima decreasing in the station order WM, NC and BH, respectively. The maximum occurrence at LN (Launceston) is later between 1400 and 1500 hrs AEST. However, there seems to be a secondary maximum at LN at about 1100 hrs AEST.

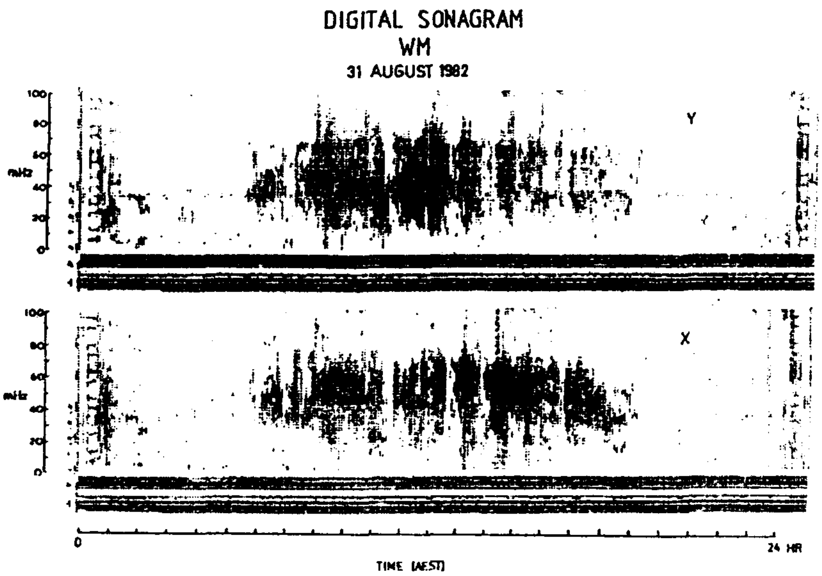

Fig. 4. Digital sonagram depicting Pc3 activity on 31 August, 1982 at Woomera **[After Ansari and Fraser(1985)]**

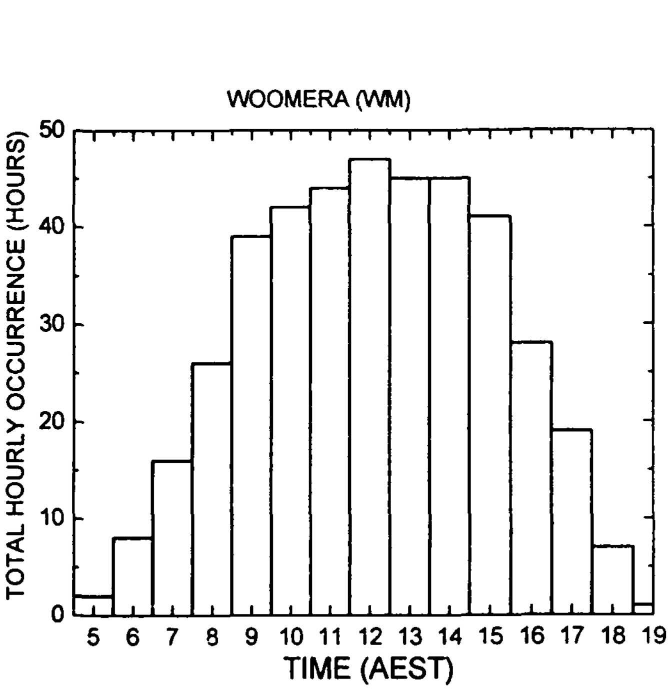

Fig. 4.1(a) Diurnal variation in PC3 activity for station WM

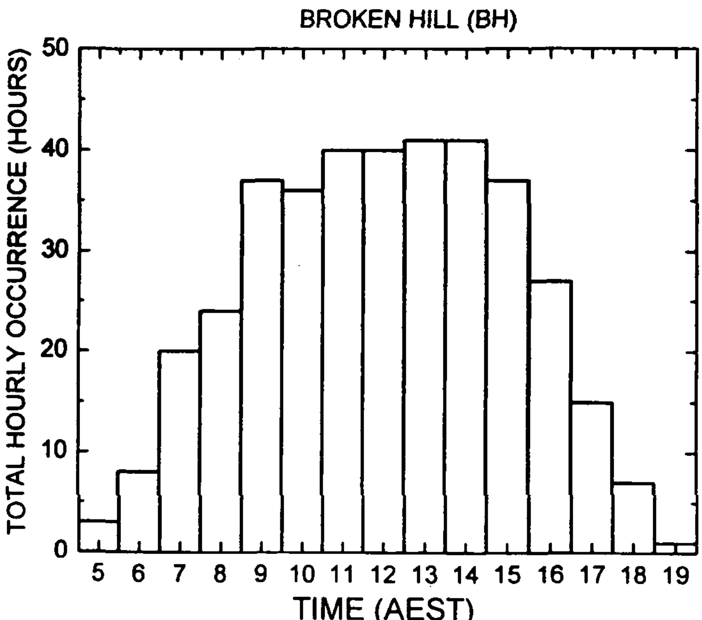

Fig. 4.1(b) Diurnal variation in PC3 activity for station BH

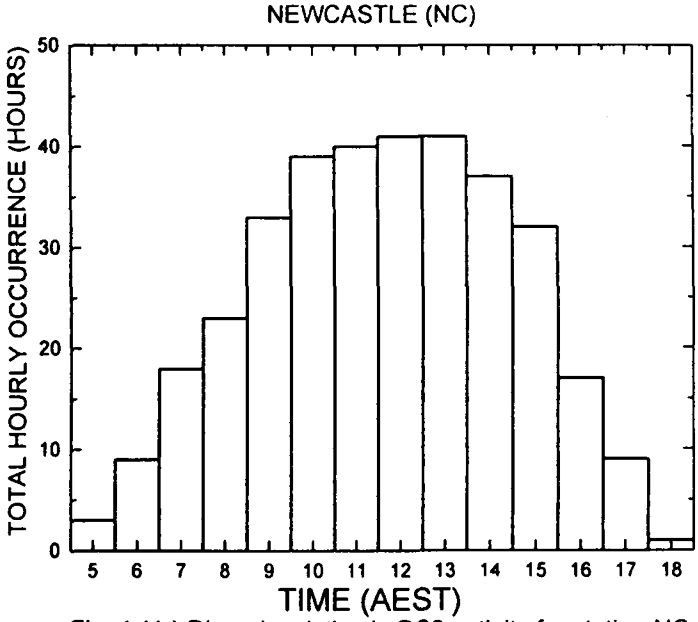

Fig. 4.1(c) Diurnal variation in PC3 activity for station NC

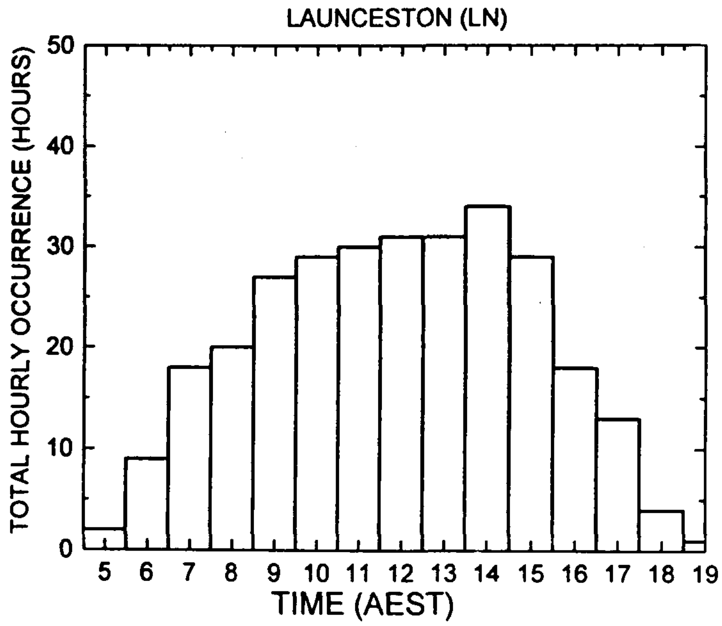

Fig. 4.1(d) Diurnal variation in PC3 activity for station LN

The variation in Pc3 occurrence with Kp values over the period 25 March- 8 June, 1982 is shown in Fig-4.2(a), Fig-4.2(b) and Fig-4.2(c) for simultaneously occurring events for the station pairs WM-BH, BH-NC and NC-LN. Two distinct maxima in Pc3 occurrence are seen at Kp= 3+, 4+ respectively. The general range of Pc3 occurrence is, however, reasonably high for Kp values in the range 1 to 5 at WM, BH and NC. At LN there is a lack of activity associated with Kp<3.

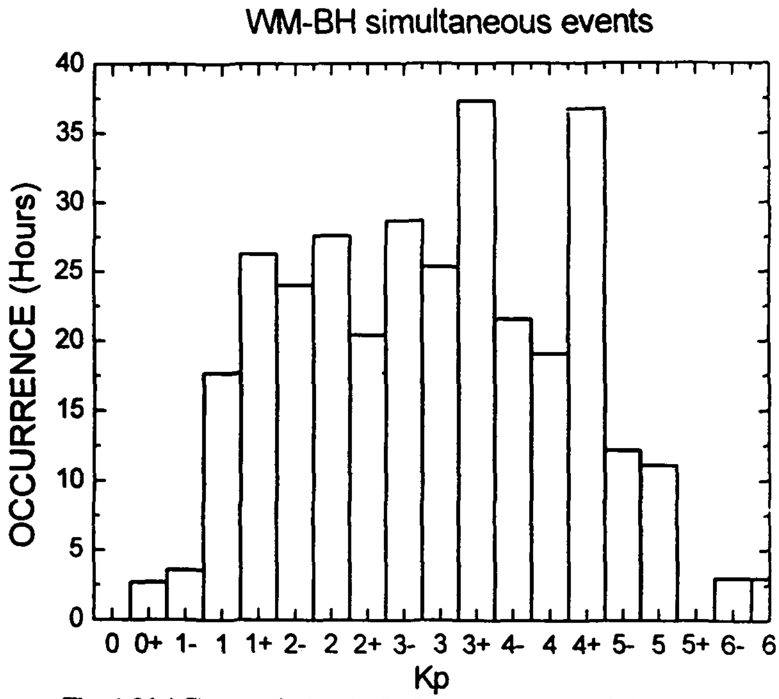

Fig-4.2(a) The variation in Pc3 occurrence with Kp values for simultaneously occurring events for station pairs WM-BH

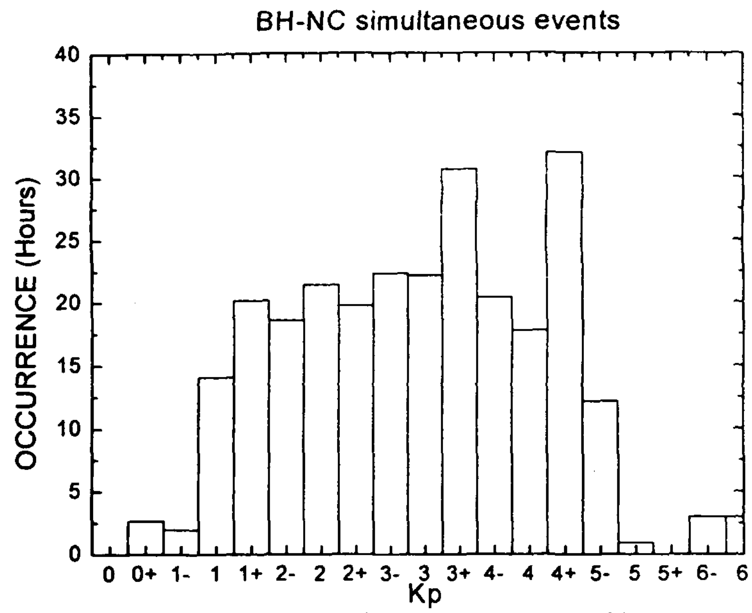

Fig-4.2(b) The variation in Pc3 occurrence with Kp values for simultaneously occurring events for station pairs BH-NC

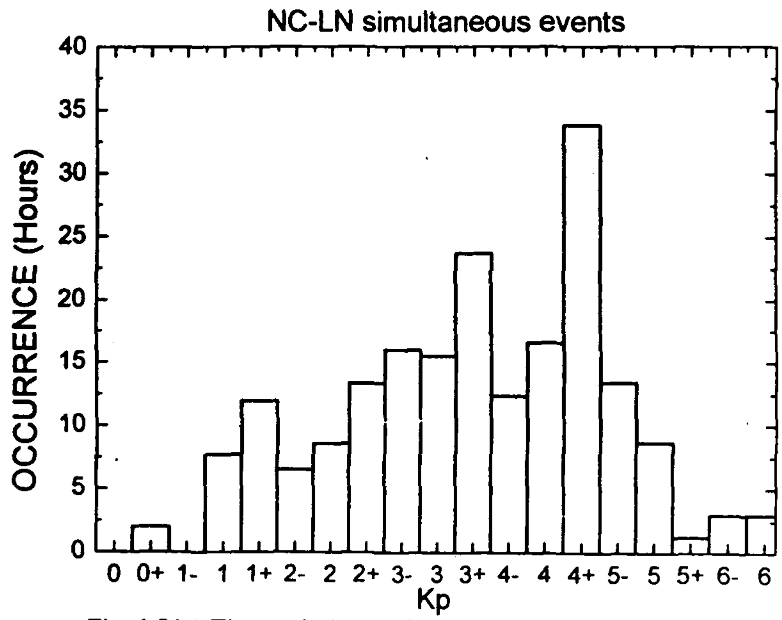

Fig-4.2(c) The variation in Pc3 occurrence with Kp values for simultaneously occurring events for station pairs NC-LN

The dependence of Pc3 occurrence probability on Kp values normalized with respect to Kp occurrence over the period 25 March – 8 June 1982 at all the four stations is shown in Fig-4.3 (After Ansari and Fraser, 1985). The figure clearly indicates that thePc3 occurrence probability is maximum for Kp = 4+ and shows a gradual increase with Kp over the range 0-4. Data beyond Kp = 4 are less reliable statistically but it is interesting to note that there is 50% probability of occurrence associated with Kp = 6-. The seasonal variations in Kp dependence of Pc3 occurrence at WM and BH are shown in Fig-4.4 (After Ansari and Fraser, 1985). The range of Kp values for Pc3 occurrence during the winter months at both the stations has extended to 7 and activity is observed up to Kp = 8,9. Furthermore, the dominant peaks in Pc3 occurrence at both the stations have shifted from 4+, 3+ in the local autumn to 4-, 3- in the local winter. However, the general range of Kp values for Pc3 occurrence over the total period (25 Mar.- 31 Aug.1982) remains unchanged in the 1 to 5 range. The seasonal variation in the dependence of Pc3 occurrence probability normalized with respect to Kp occurrence shows similar behavior as in Fig-4.4.

<u>4.3 Discussion and Conclusion</u>: -

The noon maxima [Fig.4.1(a), 4.1(b)& 4.1(c)] observed in Pc3 occurrence at the azimuthal stations WM, BH and NC, and the essential absence of activity during local night hours as well as during the local afternoon hours is similar to that reported in the past [Jacobs et. al. (1960), Prinkner et. al. (1972), Prinkner et. al. (1973), Lanzerotti et. al. (1981), Ziesolleck et. al. (1994), Zanandrea et. al.(2004)]. It can be seen in Fig.4.1(d) that the occurrence rate is lower at LN than the other stations. With the limited data available it is not possible to state whether or not this

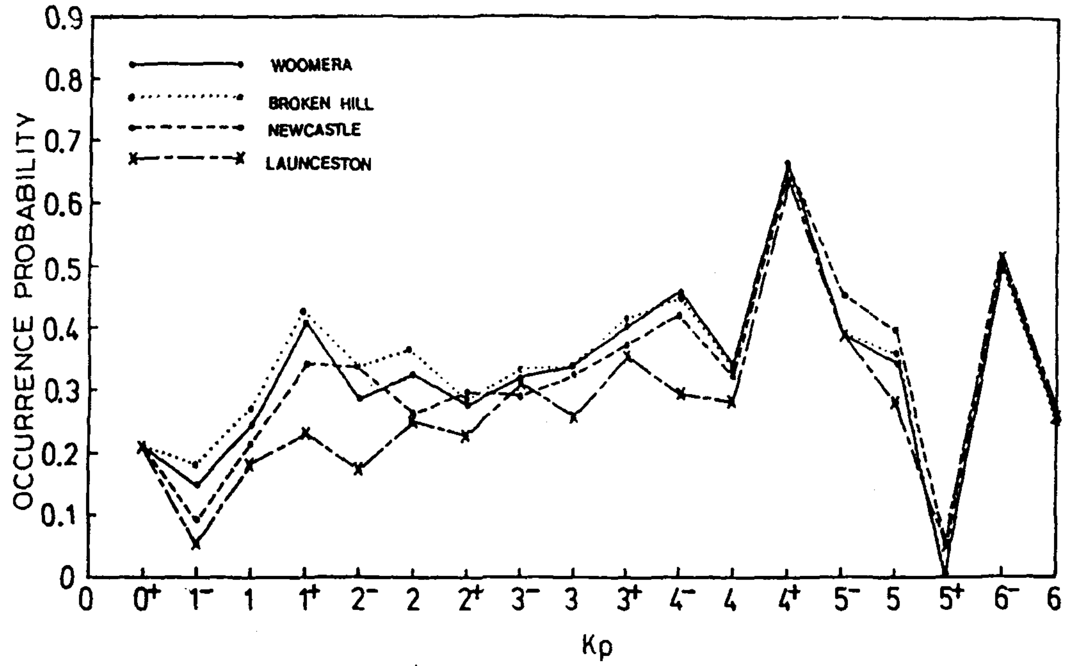

Fig.- 4.3 Dependence of Pc3 occurrence probability on Kp values normalized with respect to Kp occurrence at WM, BH, NC and LN.

(After Ansari and Fraser, 1985)

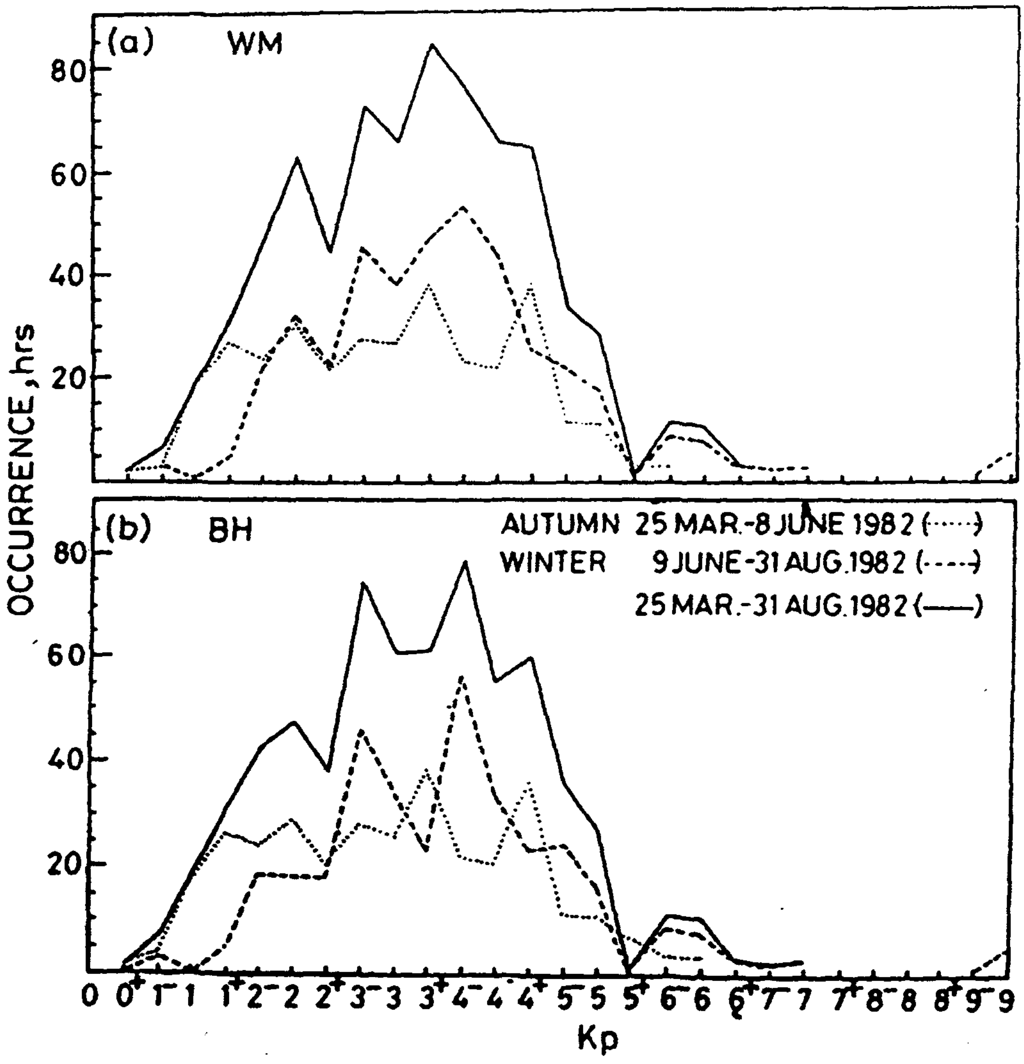

Fig. 4.4 Seasonal variation in Kp dependence of Pc3 occurrence over the specified time intervals at: (a) WM and (b) BH. **(After Ansari and Fraser, 1985)**

indicates latitude dependence in Pc3 occurrence. Saito [1969], Kuwashima et al. [1979] and Zanandrea et. al.[2004] reported prenoon maxima in Pc3 occurrence at low latitudes and this seems to be a characteristic of the Japanese and Brazilian stations. The prenoon maximum at LN at a higher latitude, however, occurs between 1100 and 1200 hrs AEST and a main peak occurs in the afternoon between 1400 and 1500 hrs AEST. This double peak is often seen at middle latitudes [Saito, T. (1969)]. Hutton [1965] has reported three peaks in the occurrence at equatorial latitudes with the main peak occurring during the evening (1800 –2000 LMT) hours. The single midday peak in the Pc3 occurrence seen at low latitudes is an important result that must be considered when postulating generation mechanisms. It indicates that waves are predominantly generated around noon. In contrast to this Pc5 pulsation indicates both morning and afternoon peaks, which relate to waves generated at the magnetopause at these time by Kelvin-Helmholtz instability [Ziesolleck al. (1994), Clauer et. al. (1997)]

The variation in Pc3 occurrence with geomagnetic activity as indicated by the Kp index (Fig.4.2) shows that Pc3 pulsations occur for Kp values in the range 1 to 5. This agrees with the previous studies of Voelker [1968], Channon and Orr [1970], Gupta and Stening [1971] and others. An important latitudinal variation is evident in Fig. 4.2. The higher latitude station LN shows less activity over Kp = 1-3 than the station at the lower latitude. The seasonal variation in the Kp dependence (Fig.4.4) shows that occurrence in the local winter and autumn months is more or less similar for $Kp \leq 5$ and is, therefore, independent of season over this range of Kp values. It is also worth noting that Pc3 activity in winter is observed for $5 < Kp \leq 9$. It should, however, be remembered that these results are based on only a little more than five months of data. Theoretical modeling incorporating magnetospheric parameters is in progress.

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